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PRELIMINARY MEASUREMENTS OF TEMPERATURES AND WINDS ABOVE 50KM OVER WALLOPS ISLAND, VIRGINIA

William Nordberg and Wendell Smith
Goddard Space Flight Center
Greenbelt, Maryland

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SUMMARY

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Seventeen successful rocket grenade experiments were conducted at Wallops Island, Va. (38°N lat.), during the period July 1960 to June 1962. The purpose of these soundings was to describe further the atmosphere above 40 km within the framework of a previous analysis based on the IGY results at high and low latitudes. The soundings were distributed through all seasons; and some were conducted in conjunction with sodium release (above 80 km) and small meteorological rocket experiments (below 50 km). Preliminary results from the first ten grenade soundings are presented here.

Comparison of grenade with sodium results shows an abrupt change in the physical nature of the circulation pattern between 70 and 80 km. Below this altitude, the previously described seasonal circulation pattern exists while above it no regular seasonal variations can be detected. The most characteristic phenomenon for this region is the very narrow jet-stream-like band of wind at the 100 km level combined with extremely high wind shears.

The temperature structure at Wallops Island indicates the same mesospheric heating in wintertime as has been observed at Churchill. During periods of undisturbed easterly circulation, summer temperature profiles at Wallops Island exhibit the same features as typical low latitude profiles previously observed. When the easterly circulation becomes disturbed, the temperature profile becomes very similar to previously observed summertime profiles at Churchill. We find that during wintertime the atmosphere over Wallops Island still lies within the region of a strong cyclonic vortex.

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INTRODUCTION

As a result of several series of rocket grenade experiments, the majority of which were conducted during IGY, attempts were made to describe the seasonal and geographic variability of the structure of the atmosphere between 30 and 90 km (References 1, 2, and 3). Some of these results were confirmed during IGY by other rocket soundings using falling sphere (Reference 4) and pressure gage techniques (References 5 and 6). The description of the structure of the upper stratosphere and the mesosphere given in Reference 1 was primarily based upon characteristic differences, derived from relatively few soundings, between IGY experiments at Churchill, Canada 59°N and pre-IGY experiments at White Sands, New Mexico 33°N. In addition, results from a small number of soundings at Woomera, Australia 31°S (Reference 7), Johnston Island 18°N (Reference 8), and Guam 12°N (Reference 3), confirmed the picture. The salient features of this rather rudimentary picture were:

1. The large variation of the temperature profile in the 60 to 90 km region between high and low latitudes or between summer and winter at Churchill (Figure 1) with large and multiple temperature maxima in the winter-mesosphere at Churchill (Figure 2).
2. The existence of an extremely strong cyclonic circulation system up to 80 km over the entire winter hemisphere, which still prevails, much more weakly, in the equatorial zones. This vortex is replaced by anti-cyclonic circulation of lesser intensity for the summer hemisphere, again reaching far into the tropics (Figure 3).
3. The observed breakdown of the wintertime circulation up to 70 km at Churchill where meridional circulation in the stratosphere and mesosphere preceded the occurrence of a typical explosive warming at lower levels (Figure 3, Reference 2).
4. The systematic summer-winter variation of pressure, temperature, and density at high latitudes as opposed to low latitudes where individual variations in these parameters appear to be random.

The most surprising and least explicable of these features was the wintertime heating at the 60 to 90 km level observed at Churchill. Recent attempts by Kellogg (Reference 9), Haurwitz (Reference 10), and Maeda (Reference 11) to explain this phenomenon were based on these high latitude observations

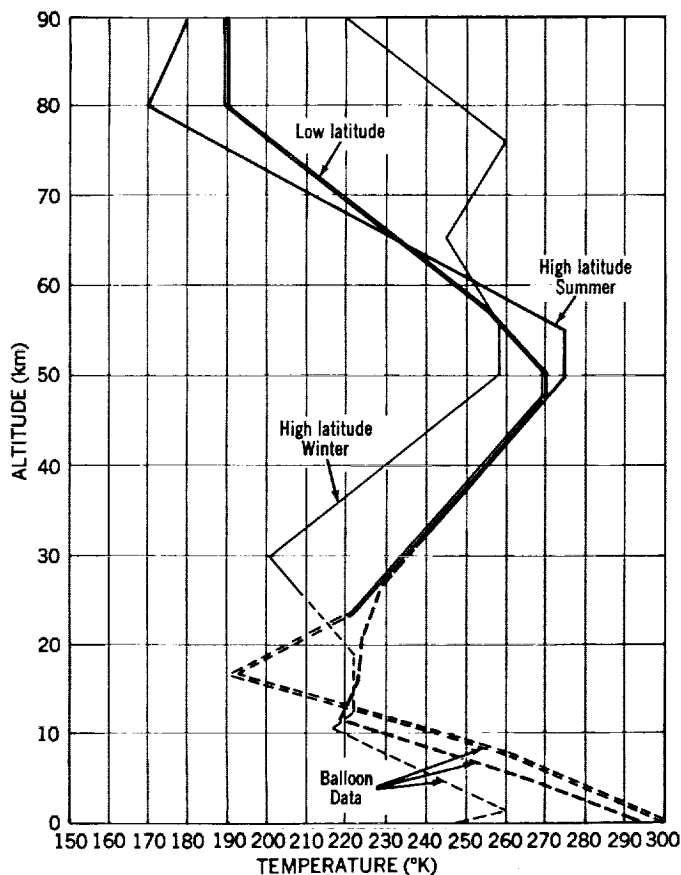


Figure 1—Comparison of temperature profiles for high and low latitude atmospheres (30-90 km).

We intend to describe the scope of these soundings and present the preliminary results available at this time.

THE ROCKET EXPERIMENTS

Balloon soundings provide measurements of the atmospheric structure parameters (pressure, density, temperature, and winds) up to about 30 km. Small, and relatively low cost, meteorological rockets of the Loki and Arcas type have the capability to carry dropsondes to 30 or 40 km above the ceiling of balloon flights. Reliable instrumentation for these rockets is limited in general, although not in principle, to the measurement of wind up to about 65 km and temperature to about 50 km. The nature of these techniques and their limitations have been reported by aufm Kampe (Reference 12). Generally, for measurements above the mesopeak (about 50 km), more complex techniques, requiring larger and more expensive launch vehicles, must be used. The rocket grenade technique is ideally suited for the altitude range from 50 to 90 km, since it provides an accurate, simultaneous measurement of temperature and wind, and since pressure and density profiles may be derived mathematically

and on the existence of other events, such as strong subsistence at higher altitudes, events which are not susceptible to grenade measurements alone.

To substantiate this picture developed during IGY and to provide further experimental results for the analysis of the features mentioned above, we started in summer 1960 a series of rocket soundings at Wallops Island, Virginia 38°N. The idea was to concentrate as many soundings as possible at one single launch site and to obtain results distributed evenly over at least one full seasonal cycle. The major experiment in these soundings was again the rocket grenade experiment, but many launchings were closely coordinated with sodium releases — overlapping with and above the useful altitude range of the grenade experiment — yielding additional wind data from 60 to 200 km, and with launchings of small meteorological rockets covering the range from 25 to 50 km. Thus, by simultaneously launching sodium releases, grenade experiments, meteorological rocket dropsondes, and balloon radiosondes, a continuous wind profile was obtained from the ground up to 200 km.

with a high degree of precision. Detailed descriptions of the different versions of the technique have been given in References 2 and 13. Basically, it involves the determination of a temperature and wind profile from the exact measurement of the direction of sound waves arriving at the ground from a series of grenade explosions, the time and location of which must be known precisely.

At Wallops Island 12 explosive charges with their associated ejection timer, flash detectors and telemetry, plus a DOVAP tracking beacon, were carried by the Nike-Cajun vehicle, a medium range, solid propellant, two-stage sounding rocket (Reference 14).

We found that the FPS-16 high precision tracking radar at the NASA launching site at Wallops Island can adequately skin-track the second stage Cajun rocket and determine the position of the explosions with sufficient accuracy. This system eliminates the need to carry a tracking transponder aboard the rocket. However, in the firings discussed, a transponder was carried in order to use a single station DOVAP (Doppler Velocity and Position) system to determine grenade positions as a backup to and for comparison with the FPS-16 radar tracking. The single station DOVAP determines the distance to the rocket as a function of time from one single ground transmitter-receiver station much in the same way as described previously (Reference 2). In addition, an interferometer array of receiving antennas serves to determine the direction to the rocket. This tracking station was developed by J. Carl Seddon (Reference 15) especially for such experiments as the grenade experiment, requiring high precision tracking. Because of its simplicity, relative low cost, and high mobility it can be used in remote areas.

Aside from the availability of these tracking systems and other support facilities at Wallops Island, this launch site on the Eastern Shore of Virginia was also a good choice from a geographical point of view. The site represents a typical mid-latitude north of the subtropical (White Sands) and tropical (Guam) stations and considerably south of the subarctic (Churchill) station where the experiment had previously been performed. This series was the first opportunity to obtain atmospheric structure data in this altitude range at mid-latitudes of the American continent.

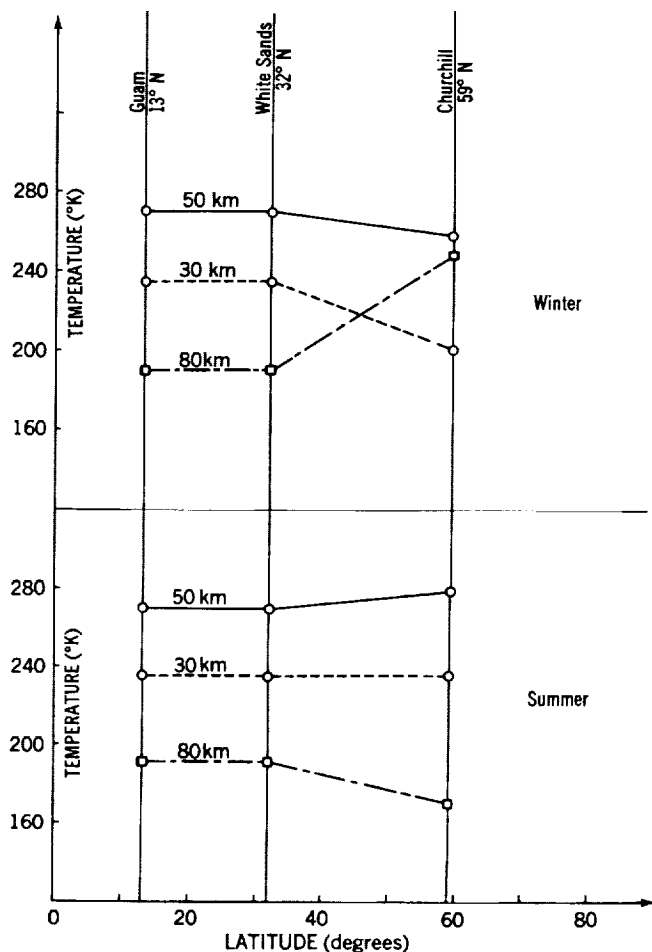


Figure 2—Variation of temperatures at 30, 50 and 80 km with season and latitude.

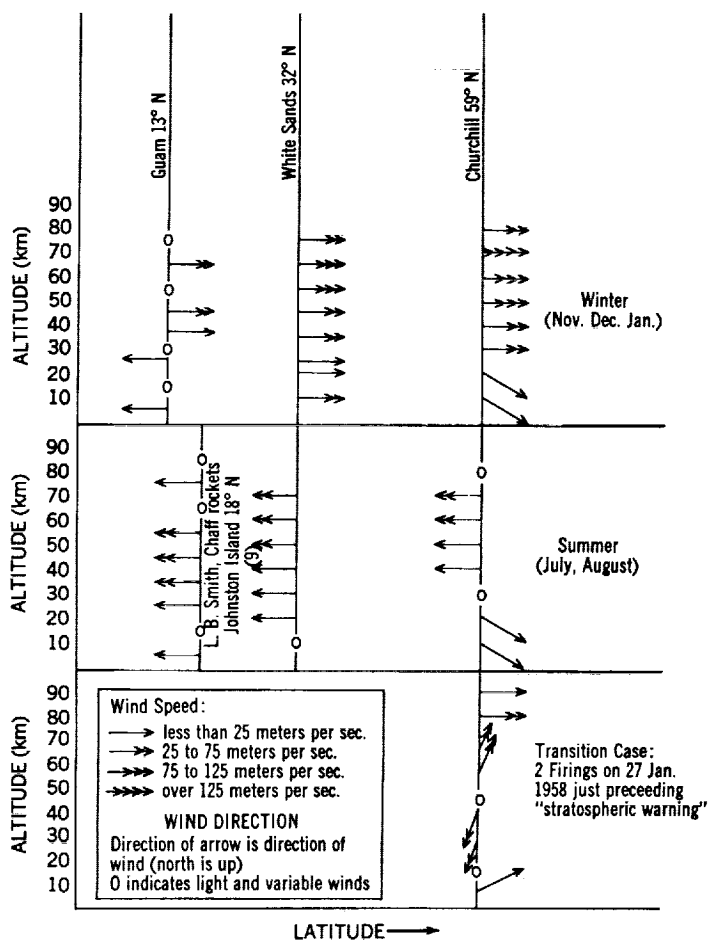


Figure 3—Summary of winds up to 90 km measured at low and high latitudes.

March 1, 1962 to June 6, 1962, there were six successful grenade soundings each launched within less than one hour of a successful sodium experiment.

For all grenade soundings, a radiosonde balloon was released within less than six hours of each grenade rocket launch. Since the number of temperature or wind measurements in each grenade firing is one less than the number of grenades exploded (for a 100 percent successful rocket, this number is 12) and since each point represents an average measurement in a layer between two explosions, it is desirable to distribute the explosions over as small an altitude range as possible. For this reason, as well as for desired comparisons, the firing of at least one small meteorological rocket, measuring winds by means of a dropsonde, was scheduled with each grenade firing. The dropsondes, usually a metallized parachute or a high drag, inflated sphere drifting with the wind, are tracked by radar and thus furnish wind information. Sometimes, the dropsondes carried thermistor temperature sensors. These dropsondes were intended to cover the altitude range from 25 to 55 km. To provide sufficient overlap, the grenade explosions were timed to go off between 40 and 95 km, leaving a layer of about 5 km between two adjacent explosions. Unfortunately, only four of the small

Since the useful range of the grenade experiment is limited to altitudes of less than about 95 km (Reference 2), many grenade firings were scheduled to coincide with sodium releases above 80 km. The sodium release experiments also conducted from Wallops Island, used the Nike-Cajun or similar launch vehicle. The method of determining wind vectors from luminescent sodium trails released by sounding rockets in the upper atmosphere had been successfully employed by Manring and Bedinger (References 16 and 17) for many years. The trails of vaporized sodium are released while the solar depression angle is near 8 degrees, so that the wind drift of the trail, still illuminated by sunlight, can be clearly photographed by three or more special tracking cameras located about 50-100 miles apart on the ground. Because of these severe time and weather restrictions (e.g., a clear sky is required) for the sodium experiment and because of operational difficulties at the launch site, as well as occasional rocket and payload malfunctions, it was not always possible to launch the grenade and sodium experiments simultaneously. Nevertheless, Table 1 shows that in the period

Table 1
Sodium Release and Grenade Experiments.

Rocket	Experiment	Launching Time and Date (EST)	Altitude Range of Successful Data (km)
Nike Asp	Sodium Release	Morning Twilight, 17 Aug. 1959	140-210
Nike Asp	Sodium Release	Evening Twilight, 18 Nov. 1959	95-205
Nike Asp	Sodium Release	Evening Twilight, 24 May 1960	85-180
Nike Cajun	Sodium Release	Morning Twilight, 9 Dec. 1960	90-140
Nike Cajun	Grenade	2259 8 July 1960	40- 82
Nike Cajun	Grenade	1850 14 Feb. 1961	40- 77
Nike Cajun	Grenade	2126 16 Feb. 1961	32- 83
Nike Cajun	Grenade	0757 5 April 1961	42- 77
Nike Asp	Sodium Release	0436 19 April 1961	80-164
Nike Asp	Sodium Release	1812 20 April 1961	80-180
Nike Asp	Sodium Release	1439 21 April 1961	80-163
Nike Cajun	Grenade	1800 5 May 1961	39- 83
Nike Cajun	Grenade	2354 5 May 1961	41- 88
Nike Cajun	Grenade	1707 13 July 1961	40- 92
Nike Cajun	Grenade	1102 14 July 1961	36- 77
Nike Cajun	Grenade	0530 20 July 1961	34- 87
Nike Asp	Sodium Release	1639 16 Sept. 1961	80-208
Nike Cajun	Grenade	1855 16 Sept. 1961	31- 63
Nike Asp	Sodium Release	0503 17 Sept. 1961	80-175
Nike Cajun	Sodium Release	1823 1 March 1962	70-134
Nike Cajun	Grenade	1901 1 March 1962	31- 83
Nike Cajun	Sodium Release	0554 2 March 1962	65-128
Nike Cajun	Grenade	0615 2 March 1962	38- 87
Arcas	Robin Sphere	1625 23 March 1962	28- 48
Arcas	Radioonde	1755 23 March 1962	28- 55
Nike Cajun	Sodium Release	1844 23 March 1962	58-140
Nike Cajun	Grenade	1854 23 March 1962	40- 90
Nike Cajun	Sodium Release	1848 27 March 1962	78-118
Nike Cajun	Grenade	1904 27 March 1962	40- 93
Nike Cajun	Grenade	0428 17 April 1962	40- 92
Nike Asp	Sodium Release	0443 17 April 1962	77-200
Nike Cajun*	Grenade	2005 6 June 1962	40- 93
Nike Asp*	Sodium Release	2056 6 June 1962	60-161
Arcas*	Radioonde	2141 6 June 1962	28- 50
Arcas*	Robin Sphere	2229 6 June 1962	28- 55
Nike Cajun	Grenade	2053 7 June 1962	40- 92

*Fired in conjunction with a pitot static tube at 1940 EST, 6 June 1962.
Also, an inflatable sphere was carried by grenade vehicle and ejected at 109 km.

meteorological rockets (Arcas) yielded useable data in conjunction with grenade and sodium soundings (Table 1). In all other cases, either the Arcas rocket or the dropsonde payload had failed or the surface wind conditions were unsafe for the Arcas rocket to be fired.

RESULTS

All soundings listed in Table 1 were successful and produced useable data. At this time, however, results are available only from the first series of ten grenade soundings conducted during the period July 8, 1960 to September 16, 1961. Data from the remaining seven grenade soundings between March 1 and June 7, 1962 are in the process of reduction.

The results of the first ten soundings are presented in Figures 4, 5 and 6. Temperature data shown in these figures are given as smooth profiles derived from up to eleven individually measured data points for each firing. Except for February 1961, the individual data points are not shown or tabulated because the intent of this paper is to demonstrate the basic characteristics of the measured temperature profiles and their relation to the previously discussed IGY results. An exception was made for the two February firings because the fine structure of the profile (due to the individually measured points) is so significant that it warrants presentation even in this general study. A full tabulation of all data, including a detailed error analysis, is now in progress and will be published at a later date.

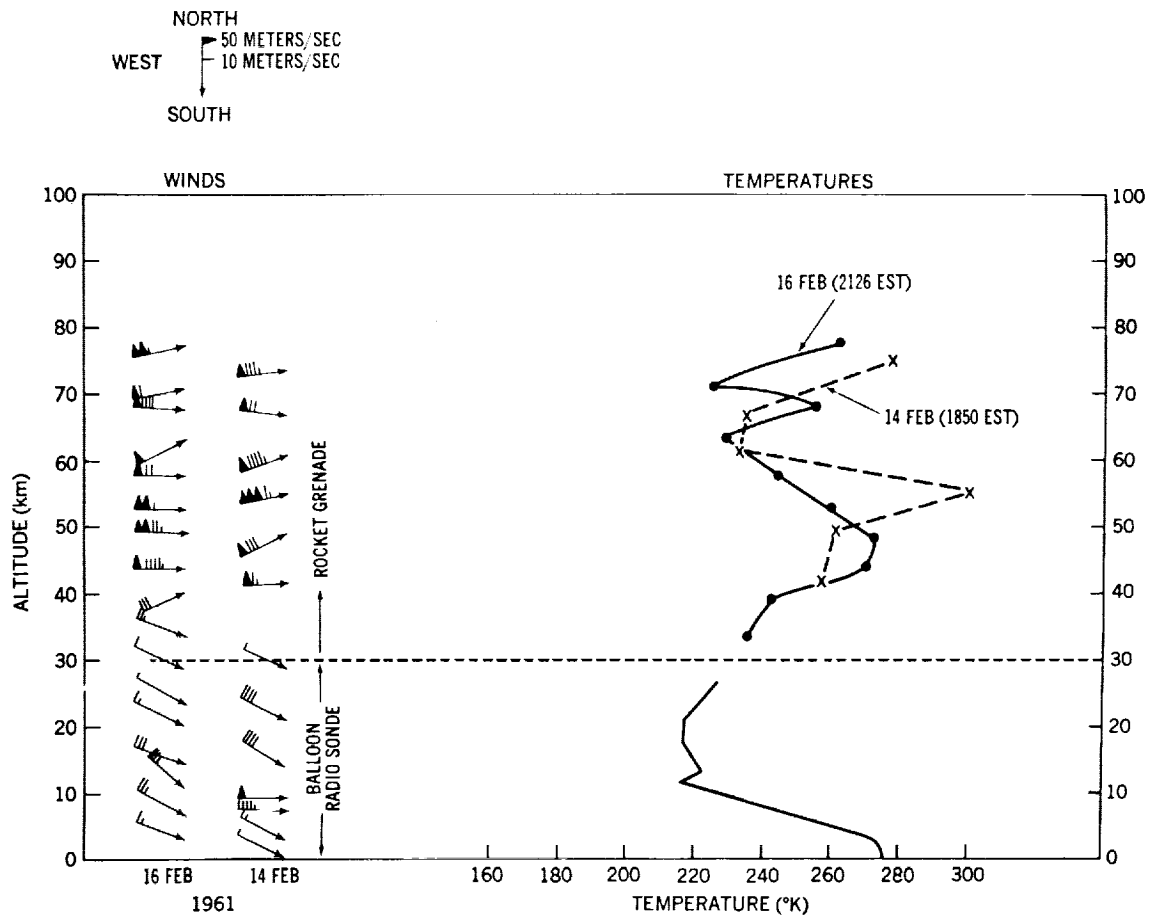


Figure 4—Temperatures and winds at Wallops Island, Va., February 1961.

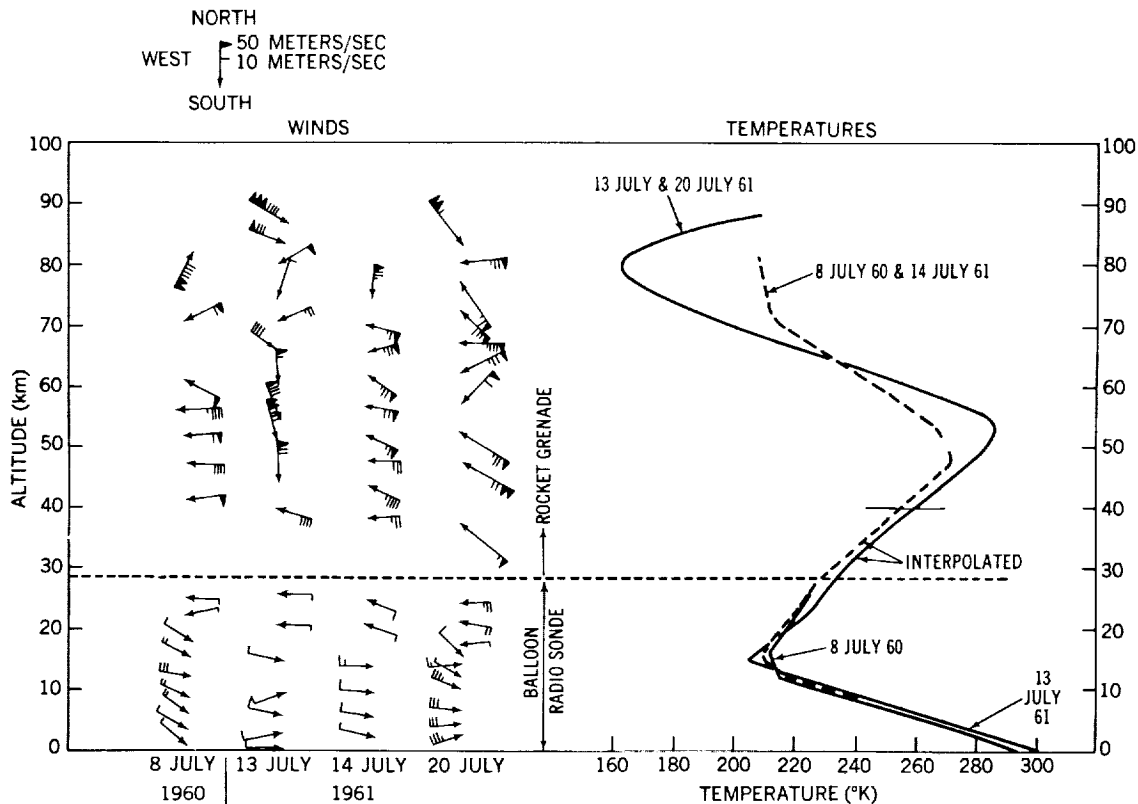


Figure 5—Temperatures and winds, Wallops Island, Va., July 1960, July 1961.

The wind data in Figures 4, 5 and 6 represent measured average values for the altitude interval between two grenade explosions. In general, the altitude of the explosion lies in the middle between two data points shown. Wind data from the 14 sodium releases prior to April 17, 1962 have been reduced and reported by Manring (References 16 and 17). Two typical wind profiles are reproduced in Figures 7 and 8; the two releases were conducted during the night of 1/2 March 1962, one at twilight, the other at dawn. A series of significant features is common to most of the 14 profiles studied—between about 80 to 90 km there is a sharp and rapid transition in the wind regime. Below this altitude, the commonly known pattern of generally uniform zonal flow, regularly reversing with season, exists. Above, there is a region where strong but highly variable winds are sandwiched between zones of relative calm. This region is characterized by the existence of remarkable wind shears. Thus far, every sounding conducted has evidenced these wind shears between 90 and 110 km. A typical case is shown in Figure 8 where, within an interval of less than 5 km, the wind speed increases by more than 100 m/sec. This jet-stream-like band of maximum wind velocity is usually located between 95 and 105 km. Immediately below and above, the wind velocities diminish almost to zero. Above 110 km, there is again a region of strong winds which may extend to altitudes as high as 200 km; however, as can be seen from Table 1, very few soundings reached above 170 km. So far, we have been unable to derive any clear cut patterns for the wind directions from these 14 firings. There is no definite variation either with season or between evening and morning soundings. In some but not all soundings, the southerly wind component (winds from the south) seems to prevail for the wind speed maximum between 95 and 105 km. Above 110 km, a strong component from the north is usually found.

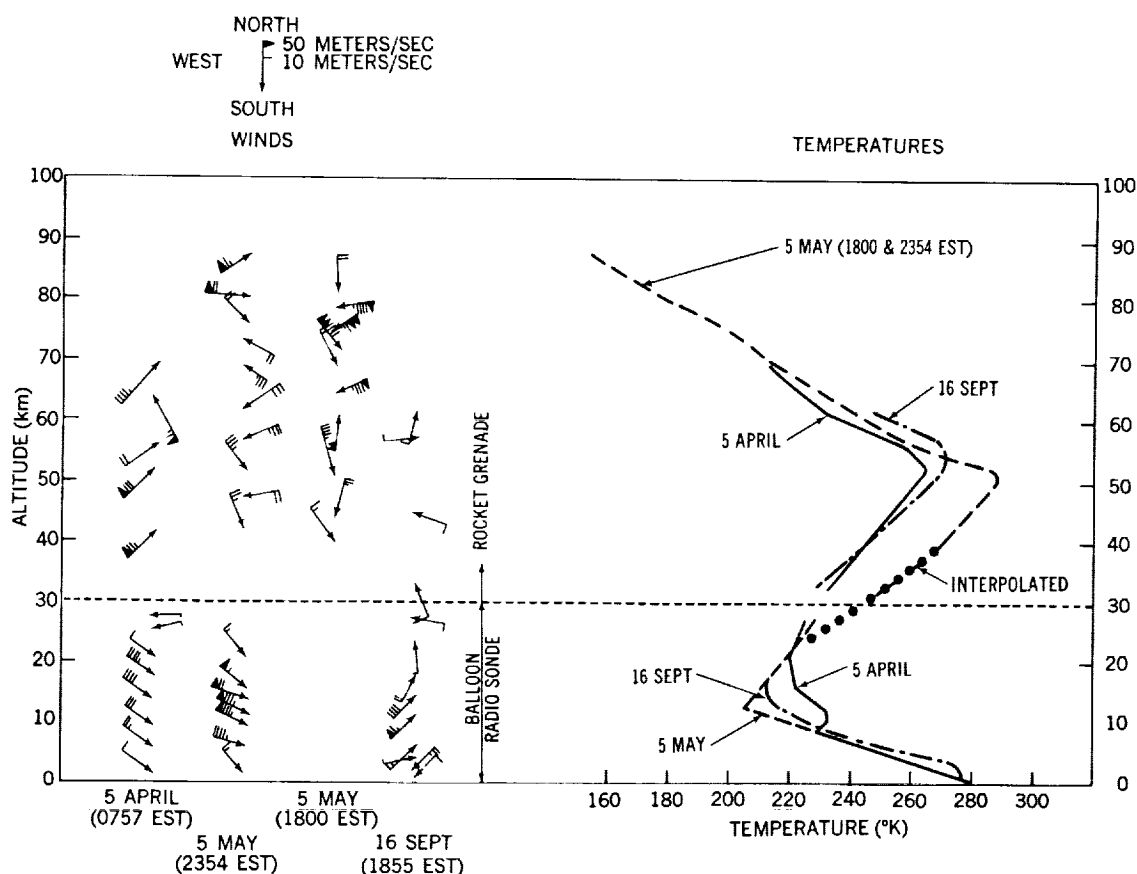


Figure 6—Temperatures and winds, Wallops Island, Va., Spring and Fall 1961.

In Figure 7, the winds derived from the sodium release are compared with preliminary wind results from a nearly simultaneous grenade sounding. Considering that the grenade winds represent averages over a relatively wide altitude range (6-8 km) and that the wind speed is rapidly changing with altitude, we find the agreement between the two methods quite satisfactory.

Below 80 km, the grenade wind results from Wallops Island show a pattern which confirms the previous descriptions of circulation at these altitudes. Both February 1961 soundings indicate very strong winds from the west. There are no significant meridional wind components at any altitude. A region of maximum wind speeds seems to exist between 50 and 60 km where west winds of 125 and 165 m/sec were observed on February 16 and February 14, respectively. These values are in accord with those observed at the same altitude at Churchill on November 12, 1956 (Reference 2).

The four summer soundings shown in Figure 5 exhibit a very interesting pattern. Two wind profiles for July 8, 1960 and July 14, 1961 again confirm the easterly circulation previously found over the summer hemisphere. Generally uniform flow from the east prevails up to 70 km. Wind speeds are much lower than in winter, with maxima not over 75 m/sec. This and the fact that the prevailing easterly flow ceases at about 70 km, are again in agreement with the Churchill observations for July and August 1957 (Reference 2). The two soundings on July 13 and July 20, 1961, however, depart

markedly from this pattern. Both show very strong meridional components. In fact, on July 13 strong winds from almost due north prevail between 45 and 60 km. On July 20, again there is a significant meridional component, although the zonal component is always from the east. Up to 55 km, the meridional component is from the south, while between 55 and 65 km, it shifts to the north. On both days, the wind speeds are unusually high (maxima between 100 and 150 m/sec) for summer conditions. In all four cases, the winds above 70 km are quite strong and irregular in direction.

Results from April 5, 1961 indicate generally a westerly component of the zonal flow, although the wind speeds have diminished appreciably when compared to the February soundings, and a meridional component from the south of almost the same strength as the westerly component is noticeable (Figure 6). An exception can be found around 60 km, where a strong south-east wind (65 m/sec) was measured. On May 5, as evidenced by both soundings on that date, the westerly flow has broken down completely. Very strong wind shears exist at all altitudes, and, although at some interspersed levels an easterly component prevails, there is no indication of the easterly summer circulation. In fact, only one out of the five soundings conducted between May 5 and July 20, 1961 showed the typical summertime flow (Figure 5).

Much in contrast to the breakdown of the westerly circulation in springtime where winds were still very strong, but not uniform in direction, the results from the sounding on September 16, 1961 indicate extremely weak winds over the whole altitude range sampled (Figure 6). Again, this is in agreement with the Churchill data

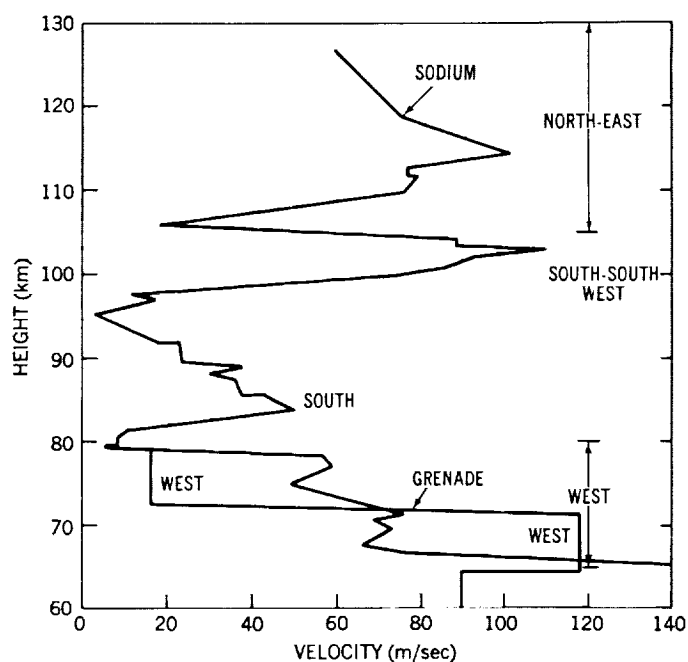


Figure 7—Wind speeds and directions from the sodium release experiment, Wallops Island, Va., sunrise March 2, 1962.

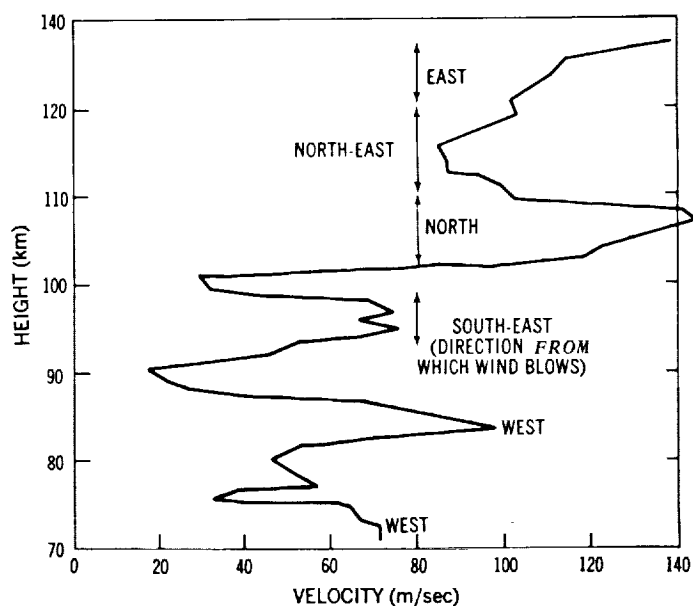


Figure 8—Wind speeds and directions from the sodium release experiment, Wallops Island, Va., sunset March 1, 1962.

(Reference 2), where relatively strong meridional flow was observed during the breakdown of the winter circulation on January 27, 1958, but very weak winds existed late in August 1957 during the transition from summer to winter flow.

Several features of the temperature results are most interesting. The extremely high temperatures above 50 km in the two February soundings, with positive and negative lapse rates rapidly alternating, is very reminiscent of the Churchill winter mesosphere (Reference 2). This heating, now observed at Wallops Island, was previously believed to exist only at high latitudes. The very high temperatures (300° and 280°K) observed on February 14 at about 55 and 75 km, respectively, seem to have penetrated to somewhat lower levels (48 and 68 km) and diminished substantially (275° and 257°K) by February 16 (Figure 4).

The four temperature profiles measured during summer should be considered in conjunction with the wind profiles. The two cases for which a uniform easterly flow prevailed (July 8, 1960 and July 14, 1961) show a typical "low latitude" temperature profile (Reference 1). The maximum ranges around 275°K and lies just below 50 km. At 80 km, a relatively shallow temperature minimum of about 200°K to 210°K is indicated. In contrast, the two soundings on July 13 and 20, 1961, where strong meridional wind components were observed, show entirely different temperature profiles. They are characterized by a high temperature maximum (about 280° - 290°K) just above 50 km and a very steep temperature minimum of about 160°K at 80 km (Figure 5).

On May 5, 1961, in both soundings we again have a very similar situation. A rather disturbed wind flow is accompanied by a high mesopeak (285°K) and a low mesopause temperature (160°K at 85 km). In contrast, the sounding of April 5 indicates a mesopeak of only about 265°K . The high temperatures above 50 km observed in February have disappeared.

The temperature profile for September 16 exhibits the same structure as the April sounding. Unfortunately, both the April 5 and the September 16 soundings did not yield any data above 70 km.

CONCLUSIONS

The wind pattern observed over Wallops Island agrees, in principle, with our previous analysis based on the Churchill, White Sands, Guam, and other, low latitude soundings, and with the circulation schemes derived by Murgatroyd (Reference 18) and Batten (Reference 19). From the coordination between sodium and grenade soundings, one may definitely conclude that these circulation patterns, most likely based upon the distribution of temperature and reflecting the meteorological behavior of this portion of the atmosphere, cease to exist above 70 or 80 km. Above this level, other factors, probably tidal forces, become increasingly prevalent in determining the circulation which does not follow the established seasonal pattern which exist at lower altitudes. Since only few of the ten grenade soundings reported here have reached above 80 km and since the sodium technique is restricted to twilight periods only, it is impossible on this basis to reach a definite conclusion in regard to this driving force behind the strong and variable wind systems above 80 km. In explaining the remarkably persisting E-region jet-stream between 95 and 105 km with its associated high shears, we will probably have to abandon the meteorologist's methods dealing with the neutral atmosphere of constant composition at lower altitudes and use those peculiar to the electrically charged ionosphere.

We conclude that, at least on February 14 and 16, 1961, the circumpolar vortex characteristic for wintertime high latitudes reached as far south as Wallops Island 38°N without any appreciable loss in strength. From these, as well as from the December 1957 results at Churchill, we conclude that the large and sporadic temperature peaks between 50 and 80 km in winter are not necessarily connected with breakdowns of the wind pattern, but are found when the established westerly circulation is very strong. The February temperature results also indicate that previous theories, explaining the high temperatures between 50 and 80 km only for high latitudes, must be revised.

The July results offer the very interesting conclusion that in summer at mid-latitudes, we may find two types of temperature distributions in rapid succession: When the circulation is uniformly from the east, the temperatures up to 80 km are in accord with those prevailing at low latitudes. During periods of severe disturbances in the easterly flow, the temperature profile changes to one typical for high latitude summers. The transition between the two types of profiles can take place within 18 hours, as evidenced by the two soundings on July 13 and 14. The conclusion that high temperatures at about 50 km and below and very cold temperatures at the mesopause are associated with a strongly meridional circulation may also be drawn from the Spring 1961 results. The September 1961 sounding seems to suggest that the change from the low latitude to the high latitude temperature profile is related to the presence of a strong meridional flow rather than to the absence of easterly circulation. The previous conclusion that this strong meridional flow is more likely to exist during the spring rather than the autumn transition period is also confirmed.

ACKNOWLEDGMENTS

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